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Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

THE
HYDRA-MATIC
TRANSMISSION

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THE HYDRA-MATIC TRANSMISSION

THE November, 1946 issue of "LUBRICATION" delineated the basic problem of automatically multiplying and controlling engine torque before applying it to the vehicles' wheels, and described one solution to the problem. The purpose of this issue is to describe another solution, the General Motors Hydra-Matic Transmission, which not only has been available as optional equipment on Cadillac and Oldsmobile automobiles during the past several years, but was also extensively employed in military equipment such as the M-5 light tank (see Figure 4) during World War II.

The Hydra-Matic Transmission illustrated in Figure 1 is a highly ingenious example of the hydraulically controlled mechanical type consisting of a special type of fluid coupling, three planetary gear trains, and the necessary manual and automatic hydraulic controls. Since the basic mechanical element of the Hydra-Matic Transmission is the planetary gear train, a brief review of this mechanism is desirable.

As illustrated by Figure 2, a planetary gear train consists of three elements, viz., a central "sun gear", a spider or "planetary carrier" having pivots for one or more "planet gears", and the outermost "internal gear." Obvious advantages of such a gear set are that all gears are always in mesh, torque loads are always distributed over several teeth, the gear is extremely compact, and the shafts of the three elements of the gear are coaxial. However, the principal but not too apparent advantage of a planetary gear is its remarkable versatility since it can be used either as a clutch, a reduction gear, a coupling or as a reversing gear by merely holding one of its three elements or by locking two of them together. A comparison of Table 1 in conjunction with Figure 2 will illustrate how these versatile effects are obtained.

As may be seen in Figure 1, the Hydra-Matic Transmission employs three planetary gear trains either singly or in combinations to produce four forward gear ratios, one reverse gear ratio, and a clutch. These planetaries are superficially similar, but differ in the methods employed for controlling them. Two of these planetaries each contain an hydraulically-applied multi-disc wet-type clutch, the engagement of which converts the planetary gear to a solid coupling. All of the planetaries operate around one or more of the four coaxial shafts of the transmission which makes a very compact and rugged assembly. The very compactness of the transmission however, makes a brief explanation of the interaction of its parts quite difficult in a short article such as this.

During the following general description of the planetaries and other features of the Hydra-Matic Transmission, the reader is advised to occasionally refer to Figure 3, a schematic diagram.

No. 1 (FRONT) PLANETARY

The sun gear, brake drum and the three steel clutch driven discs (1) are fastened together and rotate freely around the intermediate shaft unless otherwise restrained. The planetary carrier and clutch hub with its four fibre-faced driving discs (1) are keyed to the intermediate shaft and always rotate with it. The internal gear is splined to and driven by the flywheel cover, and is therefore always mechanically connected to the engine. The clutch

(1) Earlier models used five steel driven and six bronze driving discs.

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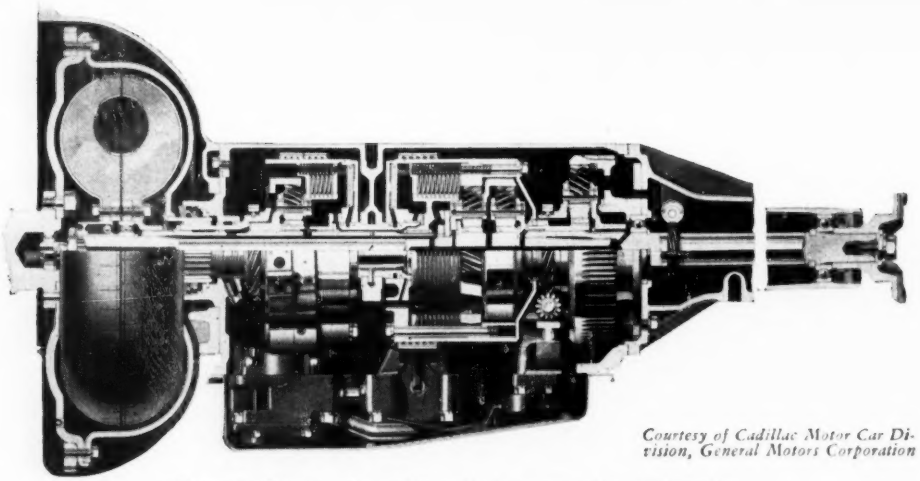


Courtesy of Cadillac Motor Car Division, General Motors Corporation

Figure 1—Cross Section of Hydra-Matic Transmission—1941 Series

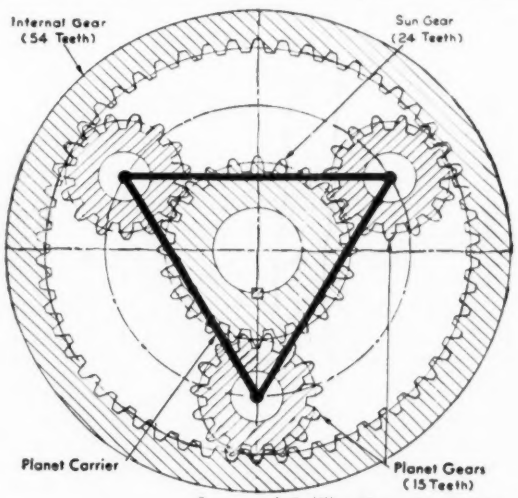
plates are normally disengaged but may be engaged axially by application of oil pressure to a single annular hydraulic piston (2), the result being to lock the planetary carrier and intermediate shaft to the sun gear. A stationary friction brake band is arranged to contract around and hold the brake drum stationary when activated by the application of oil pressure to a hydraulic piston or "servo"; otherwise it is kept released by oil and/or spring pressure. Both the clutch and brake band are normally disengaged by spring action; either may be independently applied of the other. However, both clutch and brake are never simultaneously applied, since this would stall the engine by locking it solidly to the transmission case.

No. 2 (CENTER) PLANETARY

The sun gear is an integral part of the main shaft and is therefore always driven by the driven torus of the fluid coupling. The planetary carrier has four planets and is an integral part of the output (propeller) shaft. The internal gear is screwed to the brake drum which also carries seven steel driven clutch plates (3) and a flange connected to the sun gear of the rearmost or #3 planetary. The clutch hub of this unit is splined to the rear end of the intermediate shaft and carries eight composition-faced driving discs (3). Like those in #1 planetary, the clutch discs are normally held disengaged by twelve springs (4) but may be engaged axially by application of oil pressure to a single annular hydraulic piston (5). In this planetary however, engagement of the clutch discs locks the intermediate shaft to the internal gear and brake drum, thus converting the assembly into a solid coupling.

A stationary friction brake band is arranged to contract around and hold the brake drum stationary when activated by a "servo". Unlike that in the number one planetary however, this "servo" contains a powerful spring so arranged that the brake band is normally engaged unless and until oil pressure is applied to the "servo" piston to counteract spring pressure. Furthermore the hydraulic control system and the "servo" are so arranged that hydraulic pressure is used to assist the "servo" spring in holding the brake when the planetary is in reduction, and the assisting force is increased as the engine throttle is opened. In other words No. 2 planetary is normally "in reduction".

The No. 2 planetary is of very substantial design since it is used in all four forward gears as well as



Courtesy of Cadillac Motor Car Division, General Motors Corporation

Figure 2—Planetary Gear Train, Schematic

(2) Earlier models used six small pistons.
(3) Earlier models used ten steel driven and ten bronze driving discs.
(4) Earlier models used six springs.
(5) Earlier models used six small pistons.

in reverse gear, and is therefore required to transmit torque that has been multiplied by the front planetary. Earlier models utilized a compound or double reduction planetary at this point, which consisted essentially of two single planetaries in series.

No. 3 (REVERSE) PLANETARY

Number three or reverse planetary is the rearmost and simplest of all the three since it has neither a clutch nor a brake band. Instead of a brake drum the outer surface of the internal gear is provided with a series of coarse teeth resembling a gear. A reverse "anchor dog" slideably attached to the transmission case is manually operated by the driver's range selector lever to engage the exterior teeth on the internal gear and to thereby hold the gear stationary. The hydraulic control system of the most recent transmissions contains a blocking valve which prevents the driver from engaging the anchor until the car and reverse gear are stationary.

The sun gear of number three planetary is an integral part of and driven by the internal gear of number two planetary. The planetary carrier of number three planetary is splined to the output (or propeller) shaft. The internal gear is normally free and merely idles around the output shaft unless manually locked by its anchor. It is interesting to note that the reversal of drive direction does not occur in the reverse planetary, but in No. 2 planetary, No. 3 planetary merely acting as a clutch and additional reduction gear.

All of the major gears in the transmission are of the spiral type, the resultant axial thrusts being opposed by bronze or steel thrust washers.

Table 2 gives a detailed analysis of the interaction of the planetaries, the route of torque flow through them, and resultant gear reductions or torque multiplications.

FLUID COUPLING

The fluid coupling (see Figures 1 and 3) is of a unique design composed of an oil-tight flywheel cover, the rearmost (driving) torus, and the forward (driven) torus, all three elements being mounted on separate coaxial shafts, and therefore capable of being rotated independently of each other. The flywheel cover is bolted to the engine flywheel and transmits all engine torque into the transmission through the short flywheel neck shaft and the internal gear of No. 1 planetary to which it is always connected. The driving (rearmost) torus is splined to the intermediate shaft and receives torque either from No. 1 Planetary Carrier or No. 2 clutch hub. In order to cushion torsional shocks, that might be applied, the hub of the flywheel cover contains six helical springs interposed between the hub and the cover. The driven (foremost) torus receives torque from the driving torus and transmits it through the mainshaft to the sun gear of No. 2 planetary. The side walls of the compartments in both torus members are radial. Within each of four groups the width of the compartments is increased

TABLE 1
VERSATILITY OF THE PLANETARY GEAR

To use as a	*Sun Gear*	*Arrange for Planetary Carrier*	*Internal Gear*	*Results: Torque Output from*	*Reduction Ratio**
Clutch (disengaged)	Torque Input (clockwise rotation)	Free	Free	None	None
Reduction Gear	Torque Input (clockwise rotation)	(Torque Output)	Held Stationary	Planetary Carrier (Clockwise rotation)	2.25/1
Solid Coupling	Torque Input (clockwise rotation)	to be locked together**		Planetary Carrier (Clockwise rotation)	1/1
Reverse	Torque Input (clockwise rotation)	Held Stationary	Torque Output (counter clockwise rotation)	Internal Gear (Counter-clockwise rotation)	2.25/1

*With gears having the particular numbers of teeth shown in Figure 3.

**The same effect is obtained when either the sun gear and planetary carrier, or the sun gear and internal gear are locked together.

logarithmically to avoid formation and transmission of fluid pulsations at any one critical frequency. Although physically located at the flywheel, the torus members of the fluid coupling are actually and mechanically interposed between Number 1 and Number 2 planetaries, hence the fluid coupling is able to exert its inherent smoothness and characteristic infinite gear ratio influence over all four forward and the single reverse speeds. Furthermore in first or starting gear, the reduction of Planetary unit No. 1 permits the fluid coupling to operate at only 7/10 of engine speed, hence any coupling "drag" and resultant tendency of the car to "creep" in first gear at engine idling speed are thus minimized. In addition a study of Fig. 3 and Table 2 will show that in third and fourth gears the brake drum band and the internal gear of planetary No. 2 are unrestrained with the result that the planetary "splits" or divides the torque applied to it, only forty percent of the whole being transmitted through the fluid coupling and the remainder through purely mechanical channels. By this means the already extremely small slip of a fluid coupling at driving speeds is more than halved. The fluid coupling is kept under an oil pressure of 30 pounds per square inch, any excess oil being relieved to the transmission lubrication system.

CONTROL SYSTEM

The control system of this transmission is almost completely hydraulic and is conspicuous in its ingenuity. While a detailed description of all parts is impractical within the confines of this article, the following general "high spots" will illustrate the nicety with which the design has been worked out.

The manual or drivers portion of the controls consists simply of the speed range selector lever on the steering column, and the foot throttle. The conventional clutch pedal and clutch are conspicuously absent. The selector lever and foot throttle are mechanically linked to the transmission and permit the driver to over-rule or direct its functioning which is wholly automatic otherwise.

The brain of the hydraulic control system is centralized in a small complex die casting within the transmission called the control valve body. In other words the function of the control valve body is to receive, interpret and integrate directions both from the driver and from the remainder of the transmission, and to apply or remove controlled oil pressures at the proper times and sequences to the clutches and bands of the planetaries. All of the several valves within the control body and elsewhere in the transmission are of the cylindrical piston type, and many are "stepped" to two or more diameters to permit their use as differential or balanced valves. The three "shift valves" are outstanding examples since they receive calibrated spring pressures and two or more oil pressures of different intensities which are usually opposed. When the resultant forces on each

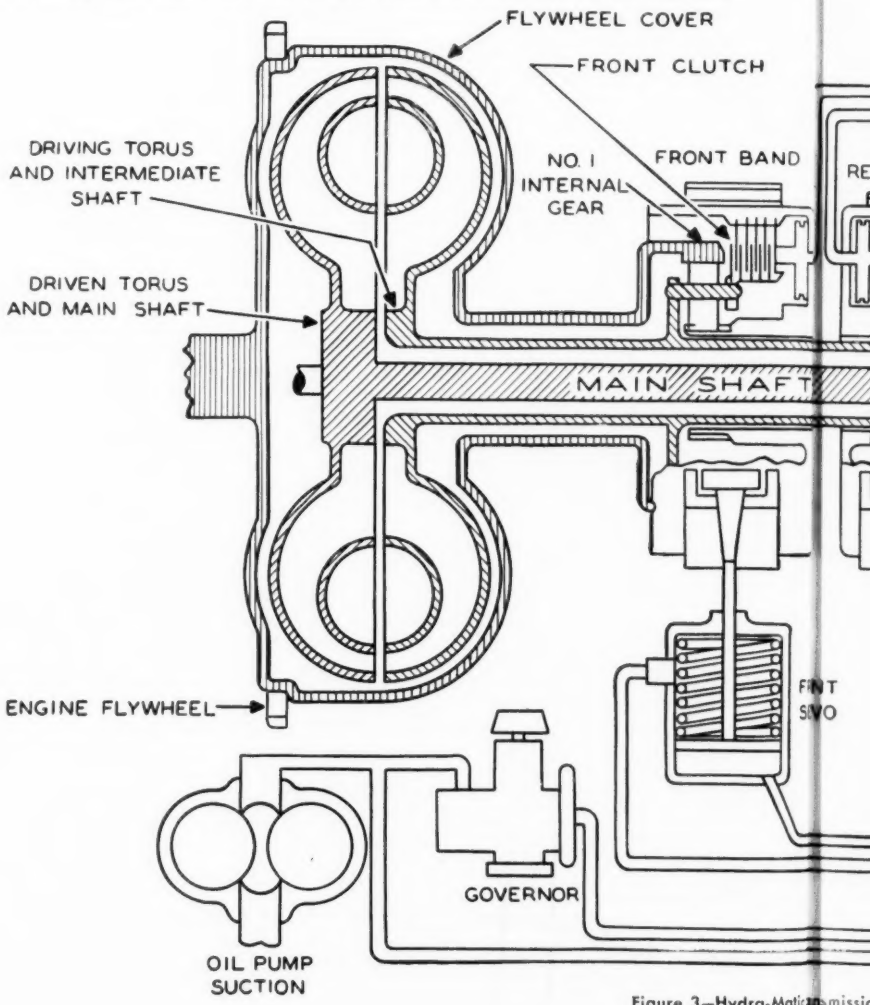
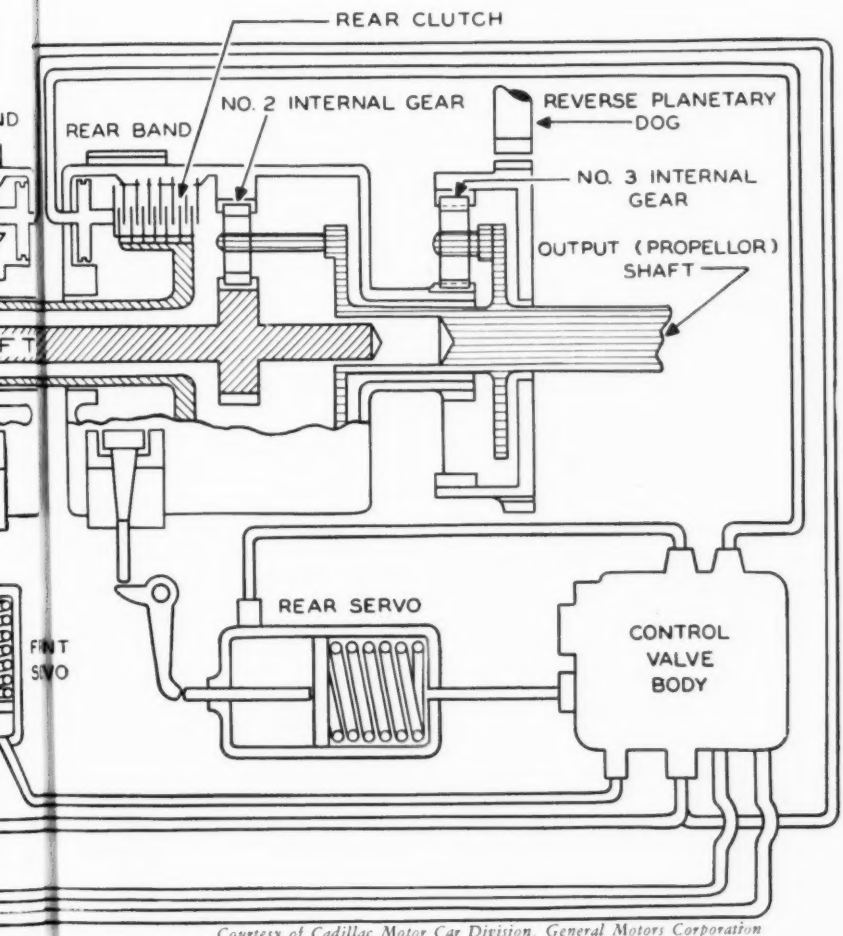


Figure 3—Hydra-Matic transmissio

shift valve are nearly equalized, the valve shifts to uncover intake or discharge ports connected to the appropriate clutches and brake bands (see Table 2) and a gear shift occurs.

To provide the requisite controlled oil pressures the transmission contains two different oil pumps, with a common intake screen. The first pump is concentric with and driven by the front planetary internal gear at the extreme forward end of the transmission, consequently it delivers oil pressure up to a maximum of eighty pounds but only when the engine is running.

The second or rear oil pump is driven by the output (or propeller) shaft and is combined with the hydraulic governor: the latter remotely resembles the historic "flyball" governor and regulates oil pressure by means of centrifugal action on its two independent and differently-weighted valves. Car speed as reflected by the governors two discharge pressures, is one of the factors which determine the car speed at which shifts will occur. The other factor is throttle position which is of course regulated by the driver and which is cleverly converted to a proportional hydraulic pressure by means of a throttle and T-valve within the control body. Left to its own devices the transmission will shift gears progressively as the certain definite car speeds shown in Table 3 under "minimum throttle" are attained. However, by merely pressing upon his foot throttle, the driver increases the hydraulic pressure opposing the governor pressures and thereby postpones or delays shifting until somewhat higher car speeds (see Full Throttle, Table 3) have been attained.



Courtesy of Cadillac Motor Car Division, General Motors Corporation

-Matic Transmission—Schematic

As indicated in Table No. 3, gear shifts in upward direction (from first to second, second to third, and third to fourth) occur in progressive order, although the car speed at which they occur may be regulated to a considerable extent by the driver through his foot throttle. Downshifts however do not necessarily occur in order. For example, if the car is decelerated under closed throttle, it will shift from fourth to third and thence to first (not second) speed. (The omission of second speed in these circumstances is due to the fact that No. 1 planetary is already in reduction, and the absence of sufficient throttle compensation pressure at closed throttle prevents application of the clutch and release of the brake band.)

A forced downshift from fourth to third speed is readily obtained by merely stepping hard on the foot throttle. If this is done while ascending a steep grade, and third speed still does not provide sufficient torque, the transmission will automatically downshift to second and if necessary first speed as the car speed decreases.

If a steep downgrade is suddenly encountered which recommends the use of the engine and a lower gear as a brake, the driver may force a downshift from fourth to second gear by merely flipping his selector lever from "Drive" to "LO" Range at car speeds under 49 miles per hour.

TABLE 2

Speed Range	*Number 1 (Front) Planetary Unit*			*Number 2 (Rear) Planetary Unit*			*Number 3 (Reverse) Planetary*		*Route of Torque Flow from Engine Flywheel Cover to Propeller Shaft*	*Total transmission reduction ratio*
	Brake Drum Band	Clutch	Reduction Ratio	Brake Drum Band	Clutch	Reduction Ratio	Internal Gear	Ratio		
Neutral Engine stopped	Released	Released	None	Applied	Released	None	Free	None	No. 1 Internal Gear-Stop	None
Engine running	Released	Released	None	Released	Released	None	Free	None	No. 1 Internal Gear-Stop	None
First (low)	Applied	Released	1.45/1	Applied	Released	2.63/1	Free	None	No. 1 Internal Gear and planetaries, intermediate shaft-fluid coupling – mainshaft – No. 2 sun gear and planetaries	3.82/1
Second	Released	Applied	1/1	Applied	Released	2.63/1	Free	None	No. 1 Unit (Locked) – Intermediate shaft-fluid coupling – mainshaft – No. 2 sun gear and planetaries	2.63/1
Third	Applied	Released	1.45/1	Released	Applied	1/1	Free	None	No. 1 Internal Gear and planetaries: further torque flow divided into two routes as follows: (a) App. 40% forward through intermediate shaft and fluid coupling to No. 2 sun gear (b) App. 60% of torque flows rearward through internal gear of No. 2 unit where it is balanced against that from route a, the resultant flowing through planetary carrier to output shaft	1.45/1
Fourth (high or direct)	Released	Applied	1/1	Released	Applied	1/1	Free	None	Locked No. 1 unit to intermediate shaft where it divides in the same manner and proportion as described under third gear operation	1/1
Reverse	Applied	Released	1.45/1	Released	Released	2.63/1	Locked Stationary	1.13/1	No. 1 Internal Gear and planetaries – intermediate shaft-fluid coupling – No. 2 Sun gear where it divides as follows: (a) No. 2 planetary gears – No. 2 internal gear – No. 3 sun gear – No. 3 planetary carrier – propeller shaft (b) No. 2 planetary carrier–propeller shaft	4.30/1

Figure 4—Light Tank M-5 *Courtesy of U. S. Army*

In an emergency this transmission may also be used as a parking brake by placing the selector lever in reverse position but only *after* the engine is turned off. This action locks the reverse unit internal gear, inasmuch as the reverse sun gear is held stationary by the normally locked drum of No. 2 planetary.

LUBRICATION

As indicated in the foregoing, the Hydramatic Transmission is an ingenious, efficient, but quite complex mechanism that utilizes such diverse mechanical and hydraulic elements as a fluid coupling torque proportioner, two multi-disc wet clutches,

TABLE 3

Steering Column Selector Position	*Foot Throttle Opening*	*Direction of Shift*	*Standard Car Speed for Shift to occur between (miles per hour)* *First and Second*	*Second and Third*	*Third and Fourth*	*Forced down shifts*
Low or "Lo"	Minimum	Up	7-14	None	None	None
Low or "Lo"	Full	Up	21-27	None	None	None
Low or "Lo"	Full	Down (Forced)				Second to First: 10-8
High or "DR"	Minimum	Up	5-7	11-14	16-20	None
High or "DR"	Full	Up	9-15	26-35	59-67	None
High or "DR"	Closed	Down				Fourth to Third: 17-13 Third to First: 4-8
High or "DR"	Full	Down	6-4	10-8	20-17	None
High or "DR"	Full	Down (Forced)				Fourth to Third: 62-13

two planetary gear sets with their friction bands and drums, two oil pumps, two servo hydraulic cylinders, master control valve, and governor, all cleverly combined to obtain automatic gear shifting throughout four forward speed ranges Since a single oil is used to lubricate and operate all of the transmission elements, it must also be extraordinarily complex since it must combine a large number of special properties such as the following:

High Oxidation Resistance

Under severe operating conditions, the oil in a Hydra-Matic Transmission can attain a temperature of 300° F. Since hydramatic oil is constantly circulated through the transmission and fluid flywheel, it is continually exposed to and intimately mixed with atmospheric oxygen at even higher local temperatures in the presence of highly catalytic metal surfaces, all of which are conducive to oxidation. The resultant sludges or varnishes from even a relatively slight degree of oil oxidation would prevent proper operation of the control valves and thereby prevent the transmission from shifting. A high degree of oxidation resistance is therefore of paramount necessity.

Viscosity and Viscosity Index

Theoretically, the fluid for the flywheel alone should have zero viscosity; however, production tolerances and loads applied to the related transmission elements require a lubricant viscosity between an SAE 10 and 20. Since the control system is essentially hydraulic, the lubricant must maintain its viscosity to a high degree through a wide temperature range. In other words, a viscosity index of at least 125 and preferably higher is desirable.

Foaming

The presence of excessive or sustained foam must be avoided since it would prevent proper operation of both the control system and fluid flywheel, depreciate or entirely remove lubrication, enhance oxidation, and promote spewing. High foaming resistance is essential.

Pour

The pour point must be low enough to permit oil flow down to atmospheric temperatures of —40° F., the lowest usually encountered in this country.

Oiliness

The smooth (non-chattering) engagement of the two wet clutches in this transmission and the number of plain bearings all recommend the special provision of oiliness characteristics.

Extreme Pressure

Although heavy gear loads are eased somewhat by the presence of the fluid coupling, the provision of some anti-scuff or extreme pressure characteristics is advisable.

Chemical Activity and Stability

The oil must not adversely affect any of the wide variety of metals, gasket materials, adhesives, clutch facings, band liners, and paint which it contacts in the transmission. Since the oil is at present canned and distributed as a spare part, it must not separate or otherwise deteriorate during storage of a year or more.

Cleanliness

The lubricant must be perfectly clean and remain so, since even minute particles of lint or any solid material may lodge in the control valves and prevent proper functioning of the transmission.

To insure the presence, proper balance and maintenance of the foregoing properties in Hydra-Matic Oil, the General Motors Corporation runs 25,000 mile tests in cars on their Proving Ground supplemented by gruelling laboratory dynamometer tests. As an example of the latter, Oldsmobile starts with a new transmission containing the test oil and forces it to shift as rapidly as possible under full load through all four gears for at least 6600 complete shifts. In other words, the oil is subjected to at least 6600 "jack-rabbit starts," each of which is equivalent to accelerating a car under full throttle from a standing stop to almost maximum car speed. A test of comparable severity as conducted by the Detroit Transmission Division causes the transmission to shift back and forth under load between second and third so that both bands and both clutches operate on each shift.

Availability

Due to the scarcity of oils meeting these difficult requirements, and to the desirability of checking adjustments whenever the transmission is refilled or replenished, the manufacturers of cars employing the Hydra-Matic Transmission purchase Hydra-Matic oil in sealed containers and resell it through their regular service outlets, much like any other spare part.

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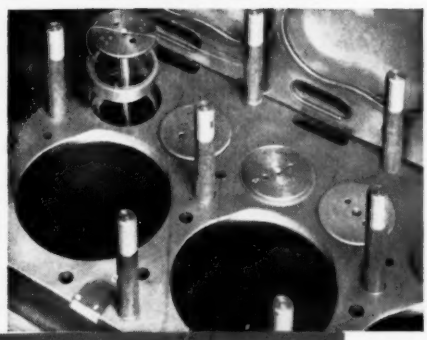

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